DOE-NE Fosters Novel International Investments in U.S. Nuclear Energy Research

By Drew Thomas, NEUP Integration Office

Nuclear energy is an international industry, but nuclear research and development has been somewhat isolated as each country individually develops innovative reactor designs, materials, and instrumentation. However, that model is starting to change.

The Department of Energy, Office of Nuclear Energy (DOE-NE) has in recent years placed an increased and more formal emphasis on coordinating with international research entities and funding sources to draw upon nuclear energy expertise from around the world.

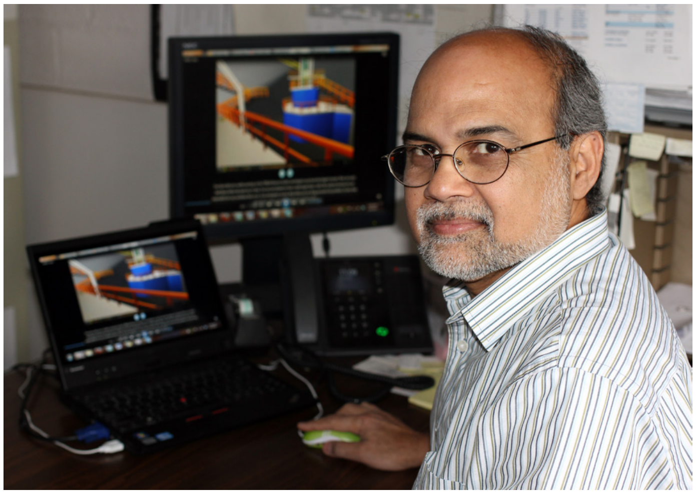
"The challenge in cultivating these relationships is multi-faceted and includes the need to match research objectives while overcoming funding uncertainties," said Michael Worley, Program Director of DOE-NE's competitively funded nuclear energy research portfolio. "Although it is a high priority for DOE-NE to employ diverse research partnerships to improve the quality and breadth of our research, United States (U.S.) government research and development funds can only be provided to U.S. institutions. To foster these valuable international partnerships, researchers in other countries must have access to funds from their own governments or other sponsors. "

Fostering these partnerships means the U.S. must share its research priorities with the international research community.

In order to more effectively tackle major research priorities, DOE launched a new Nuclear Energy University Programs (NEUP) element called Integrated Research Projects (IRP) in 2011. IRPs, which call for solutions to fairly specific, but complex capability gaps identified in the U.S. nuclear energy research portfolio, encourage highly collaborative teams that span multiple scientific, engineering, economics, and public policy fields.

Collaborations with the Engineering and Physical Sciences Research Council (EPSRC)

Beginning in 2012, DOE-NE entered into discussions with the Research Councils UK (RCUK) to develop the mechanisms by



Rizwan Uddin, a modeling and simulation expert from University of Illinois, Urbana-Champaign, assesses the performance of 'self healing' fuels for an IRP project studying ways to make fuels more tolerant to transient conditions.

which United Kingdom (UK)-based nuclear energy researchers funded by the EPSRC could participate in that year's IRP competition as collaborators with U.S. university-led applicants.

During the 2012 award cycle, over $13 million in U.S. funding was allocated for IRPs. The EPSRC leveraged NEUP proposals and the existing NEUP review process to allocate an additional £2.1 million ($3.7 million) to UK researchers who collaborated on successful applications. In so doing, over $16.7 million worth of research was initiated, significantly increasing the value of each country's investment.

"The collaboration focuses around fundamental research questions that are common to the nuclear industry around the world," said Stephen Elsby, Director of the RCUK Office in the U.S. "It makes sense to address these issues collaboratively."

This highly successful collaboration process was expanded in 2013, resulting in additional IRP partnerships and U.S./UK joint funding.

"To-date, the EPSRC partnership is by far our most successful DOE-NE competitively funded R&D collaboration," said Ken Osborne, DOE-NE University Program team lead. "We are very excited that this partnership will continue to expand in 2015 to the continued benefit of the research priorities for both countries."

The UK-U.S. collaboration initiated in 2012 focuses around three research projects to improve fuel cladding and inherent safety design in light water reactors.

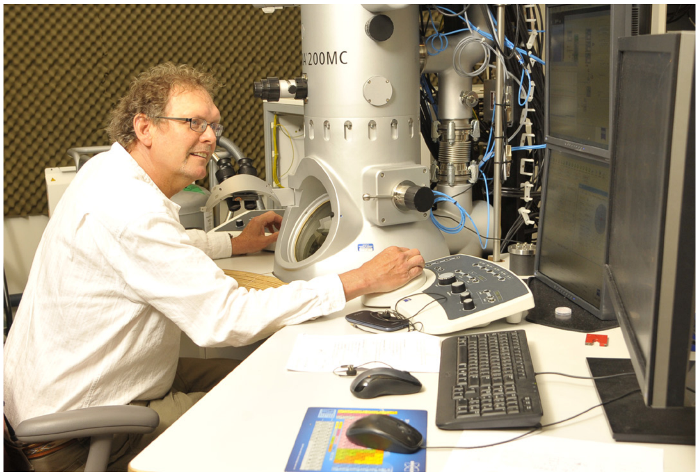
Ceramic Coatings for Cladding

The University of Tennessee is conducting one of two projects attempting to modify reactor fuels to prevent hydrogen explosion accidents, like the one at Fukushima Dai-ichi. A major technical issue with current fuels is that cladding materials use zirconium alloys, which are susceptible to oxidation, resulting in hydrogen build-up at high temperatures.

"We are comparing and contrasting different types of ceramics to find the best candidate that reduces high temperature oxidation and corrosion resistance," said Kurt Sickafus, lead researcher and professor at University of Tennessee. "With the right material, a small coating on the cladding could delay hydrogen build-up for an extended period of time, preventing explosion accidents like those seen at Fukushima."

Ceramic coatings for cladding will be applied on a microscopic level, allowing coated fuels to be used with currently operating reactors. The study will explore whether coatings have any disadvantages with thermal conductivity, a key factor in the ultimate energy output of a nuclear reactor. To fully evaluate each option, the coating needs to be fabricated, corroded, and then characterized to see which material—and which application technique—provides the best performance.

The majority of the fabrication effort is occurring here in the United States. Testing and evaluating the results of different ceramics is the only way to choose the best candidate for widespread use. After coatings are applied and tested, samples are shipped overseas for characterization to collect information about their performance. The EPSRC has contributed £996,000 ($1.6 million) to provide this expertise from UK universities. That work centers around specialized expertise and instruments at the University of Oxford, University of Sheffield, and University of Manchester.



Kurt Sickafus, senior researcher at University of Tennessee, Knoxville, uses a Transmission Electron Microscope (TEM) to analyze protective coatings deposited on Zirconium alloy cladding, a technique used to make fuels accident resistant.

"The real rate limiting aspect to this type of experimental project is characterization," said Sickafus. "Characterization is tedious, and having several institutions with highly sophisticated equipment is the only way to get results in such a short timeframe."

Tests have currently been completed at normal reactor operating conditions. Tests on transient conditions, which are abnormally high from normal operation, are expected in 2015.

Self-Healing Fuels

A project led by University of Illinois takes the coating concept a step further.

In addition to developing a coating, albeit a metal coating instead of a ceramic one, the Illinois-led team is creating a cladding that can actually heal itself.

"Adding a protective coating provides one line of defense against oxidation, which is important, but may not be enough," said Brent Heuser, lead researcher and professor at University of Illinois. "This research is groundbreaking in that the cladding material itself combats oxidation, therefore 'healing' itself to create an additional barrier."

This new type of cladding will incorporate beryllium, an element sometimes used for radiation shielding, into the cladding material. During an accident, beryllium would move toward the breach in protective coating and 'self-heal' by creating an oxide resistant layer within the cladding. By using a metal coating in conjunction with the beryllium infused cladding, this technique may prevent thermal conductivity issues that can become problematic with thicker ceramic coatings.

"That means a 'self-healing' fuel could maintain energy output while significantly decreasing the possibility of an accident," said Heuser.

EPSRC-funded collaborations, totaling £934,000 ($1.5 million), were essential to add metallurgy expertise and capabilities to the project. Metallurgy has been losing popularity in the United States for years as advanced ceramics and polymer systems have become more commonplace. Metallurgy and materials experts at the University of Manchester have already begun working on irradiated samples from the U.S. to test material performance.

Heuser stresses the advantage of the collaborative relationship with his UK partners.

NEUP International Collaborations: The Numbers 2009-2014

NEUP projects foster unique partnerships from international academia, industry, and world renowned laboratories.

Total funding from the Research Councils United Kingdom to collaborate on FY 2012 and FY 2013 IRPs — **$5,138,603**

10 — Number of collaborations with the United Kingdom (National Nuclear Laboratory, Oxford University (2), University of Cambridge, University of Huddersfield, University of Manchester (4), University of Sheffield)

Seventeen — International collaborations on NEUP R&D projects

Five — Foreign industrial partnerships

Five — Collaborations with world renowned laboratories

Number of individual collaborators working with NEUP-funded researchers on R&D or IRP projects — **31**

41.8 $ MILLION — Amount of NEUP funding to U.S. university researchers working with international collaborators since 2009

"This collaboration allows us to test more samples, involve more people, invest more money, and provide better validation of the research results," he said.

I²S-LWR: Integral Design for Large Light Water Reactors

This Georgia Tech-led project is looking to influence the design of future light water reactors, developing a new concept to incorporate more inherent safety features than ever before. The team is developing new technology and integral design from small reactors and attempting to apply those technologies to integral large light-water reactors while maintaining power output at the highest feasible levels.

The project takes a holisitic view of all materials and systems from the ground up including a redesigned vessel and primary circuit, fuel, cladding, and power conversion system. The new reactor design must be able to compete with light water reactors currently being built in the U.S., while increasing the overall safety portfolio.

"A simpler design means a reduced upfront capital cost," said Bojan Petrovic, team lead and professor at Georgia Institute of Technology. "Although there will be a higher cost for fuel with accident tolerance, it will be offset by reduced capital cost, making the new design overall economically viable."

The project has elicited widespread participation from the international community.

In addition to ten U.S. organizations, partners from the UK, Italy, and Croatia have brought expertise to the project in a variety of different technical fields including reactor physics, thermal-hydraulics and safety, and thorium-based fuels. The project has generated much of its international collaboration because of its possibilities.

"This type of international project is one that people want to join," said Petrovic. "The holistic redesign of the reactor requires expertise in all technical areas, drawing from expertise around the globe."

One such collaboration, with the University of Cambridge, will study thorium-based fuels for use in the reactor. Although not a priority in the United States, thorium fuels are of interest to UK academics, allowing both countries to leverage the project for their own priorities and research interests.

The project will provide an assessment of the feasibility of the I^2S-LWR concept. After this evaluation, DOE-NE will decide how to use technical results from the project to influence future reactor design.

Future Collaborations

The U.S./UK partnership continues to evolve. Rather than pursuing additional partnerships on the larger IRP projects, in FY 2015, the EPSRC will be providing up to £1.5 million ($2.4 million) for UK researcher collaborations on smaller research and development projects across a variety of fuel cycle and reactor concepts research areas. Research partnerships are currently being established in response to DOE-NE's pre-application call, which closed on October 2, 2014.

"This collaboration is part of our 'best with best' international collaboration policy," said Neil Bateman, Energy Portfolio Manager for EPSRC. "Our IRP collaboration has been successful, and we hope to expand collaborations to even more research groups in the U.S. by supporting small research grants in FY 2015."

DOE-NE looks to expand its research and development portfolio and will continue to pursue further opportunities to collaborate with international entities.